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Summary Progress Report

for

"Technical and Economic Analysis of Issues Related to Free Flight"

NAG 2-993

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This study demonstrates the scope and effectiveness of methods developed by the Logistics Management Institute, the Massachusetts Institute of Technology (MIT), and Phoenix Integration for analyzing the system performance and economic effects of advanced air traffic management technologies.[1] Two key questions guided the work: first, what benefits are likely to accrue to air carriers from operations on optimal routes instead of on FAA preferred routes; second, what impacts would those operations be likely to have on the challenges of air traffic management?

The Likely Benefits to Air Carriers

To address the first question, we developed methods for rapidly computing optimal trajectories for a specified aircraft between given cities, with winds aloft for a specific date, under dispatch policies that we developed in consultation with United Airlines' operations center.

Inputs to these routines are as follows. For aircraft performance characteristics, the routines use the Base of Aircraft Data (BADA) models developed by the Eurocontrol Experimental Centre.[2] These models cover more than 140 aircraft.

Winds aloft inputs are provided by data from NOAA's National Center for Environmental Prediction (NCEP) located at the Goddard Space Flight Center. NCEP's data are available for most days since the mid-1970s. Our specific studies used the wind data for calendar year 1995, which are complete except for January 20, July 11, and August 10. The data are given on a three-dimensional grid. To use them, we developed an interpolation scheme to return wind as a smooth function of arbitrary position. Rather than arbitrary smoothing, the scheme respects the fact that eastward and northward velocity components are part of a single fluid motion.

Our routine for computing flight times and fuel burns in cruise uses an exact solution for fuel burned on a flight at constant altitude and Mach number, corrected for altitude and speed changes by the total energy method. Fuel burns for taxi-out, and for terminal area maneuvering and taxi-in, were fixed. We estimated fuel for takeoff and initial climb as proportional to takeoff weight.

The general dispatch rule was to minimize fuel burn while achieving the assigned block time, if that was possible under a maximum fuel constraint. If not, flights operated for minimum time, with the maximum fuel. Flights on FAA preferred routes were allowed one step climb, while optimal routes varied their altitude and Mach number continuously. Optimal trajectories respected special-use airspace.

We used Phoenix Integration's Optimization Workbench[3] to make the optimizations. The Workbench allows a choice of three methods: modified method of feasible directions (MMFD), sequential linear programming (SLP), or sequential quadratic programming (SQP). We generally used SQP to compute optimal routes.

We compared block fuel and block time for FAA preferred routes with those quantities for optimal routes, for turbojet (B757-200) operations between seven city pairs, and for turboprop (BAe 41 Jetstream) operations between one city pair. The city pairs chosen gave a reasonably broad range of stage lengths, ranging from 2.263 nm to 474 nm.

For the turbojet, fuel savings ranged from 3 to 7 percent. Substantial parts of the savings are due to inefficient preferred routes. They are fragile, in the sense that even 15 minutes' added terminal area delays would devour them.

Turboprop savings were 14 percent for IAD–CHS and 5 percent for CHS–IAD. These results clearly are affected by the fact that the IAD–CHS preferred route is 13 percent longer than the great circle, while the CHS–IAD preferred route is only 2 percent longer. (While optimal routes may differ widely from great circles, they usually lie fairly close to those shortest-distance paths. Thus, preferred routes that depart significantly from great circles tend to be fuel-inefficient.)

We found that rescheduling operations to take advantage of shorter block times made possible by optimal routes may give 15-minute reductions in block times for flights from Boston to Los Angeles.

Impact on Air Traffic Management

We turn now to the study's second key topic, assessing how airlines' use of optimal routes instead of FAA preferred routes would affect air traffic management. For this task, we needed a model of the national airspace system (NAS) that could show the effects of differing flight paths on workloads in the FAA's air route traffic control centers and sectors, and terminal radar approach control (TRACON) centers, as well as on airports. We also required a model that could be set up and operated reasonably quickly, in not more than a few hours, because we wanted to be able to consider several cases as parts of a one-year effort.

We found no such model. Simulation models such as NASPAC[4] can produce the required outputs, but not quickly enough. Among analytic models, MIT's Approximate Network Delays (AND) model met all the study's requirements except for detailed modeling of parts of the NAS outside airports.

We have pursued two efforts to acquire the necessary capability. In one, we developed a queuing model of enroute air traffic control sectors, which can be integrated with the AND model. This work, when completed, will give an NAS model fully capable of making the assessments that we want. In the other effort, done so that we would have at least some preliminary results in the one-year study, we integrated an early version of our enroute model with queuing models of airports developed in another NASA task.[5] The resulting queuing model of the NAS, LMINET, is currently implemented with 25 airports, each with two arrival sectors and one departure sector, and 126 enroute sectors.

Our Sector Model

An FAA enroute air traffic control sector as an $M(t)/E_k/N(t)/N(t)+q$ queue. That means that arrivals to the sector are assumed to be random, in the sense that the interarrival times have a Poisson distribution. The distribution's parameter may vary with time. Service times—i. e., the times that aircraft spend in the sector—have the Erlang distribution with parameter k, a positive integer. The k parameter of an Erlang distribution describes the population's concentration about its mean. As k increases from 1, the standard deviation of the Erlang distribution decreases from 100 percent of the mean to 0.

The parameter N is the maximum number of aircraft that the sector can accommodate simultaneously. If more than N aircraft are present, some must "wait" in a "queue." Controllers impose waiting on aircraft by issuing off-course vectors and/or requests to reduce their speed.

Finally, the parameter q is the largest number of aircraft that can wait, that is, the largest number whose arrival times controllers can manage effectively by vectoring and speed changes. If more than q airplanes need to be delayed to keep a sector below its capacity N, controllers will divert some to other sectors.

We validated and calibrated this model with ETMS data and, more importantly, by discussions with controllers at the Denver Air Route Traffic Control Center and at the Denver TRACON. The ETMS data, analyzed for a sector in ZDV and a sector in ZID, substantiated the assumption of Poisson interarrival times, and indicated that $k = 3$ was a reasonable value for the Erlang distribution parameter. Discussions with controllers, held both as we developed the model and to review initial results, gave us values for the parameter N, as well as suggestions for the way N might vary, and the causes of the variations. Values of the maximum number of aircraft actually observed in ETMS data for each of the two sectors that we considered were consistent both with the discussions with controllers, and with a recent FAA publication.[6]

We developed the sector model for enroute sectors. Also, a controller in the Denver TRACON who reviewed the sector model said that its structure and results seemed reasonable as a model of TRACON arrival and departure sectors.

Results Using LMINET

We carried out preliminary calculations using LMINET, with TRACON and enroute sectors modeled with M/D/N queues, in which all aircraft spend the same time in the sector. These showed that the network model reproduced interactions reported by airport controllers: closing the New York airports starves Boston of aircraft for departing flights within about three hours, because so many arrivals at Boston come from New York.

We found that using optimal routes for the winds of July 1, 1995, and for the winds of August 1, 1995 in LMINET, caused significant variations in demands at certain model sectors. Nevertheless, these variations did not materially reduce peak demands in certain sectors at certain hours. These highly preliminary results do not support the hope that simply using optimal routes will materially reduce the density of air traffic in congested areas.

References

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